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# THE $p_{\rm T}$ SPECTRUM OF HEAVY QUARKS IN PHOTOPRODUCTION


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We illustrate a formalism that allows to match the next-to-leading order cross section for the photoproduction of heavy quarks to the cross section obtained by resumming logarithms of $p_T/m$ to the next-to-leading accuracy, thus giving a sensible prediction for any value of $p_{\rm T}$. We present a comparison between our predictions and H1 and ZEUS data.


## 1 Introduction

The computations of the cross sections for the production of open heavy flavours at fixed-order (FO) in perturbative QCD have been so far carried out at the next-to-leading order (NLO) accuracy for all possible production mechanisms. For single-inclusive observables, when the transverse momentum $p_{\rm T}$ of the quark is much larger than its mass $m$, terms containing $\log(p_{\rm T}/m)$ become large in the FO cross section, which is thus no longer reliable. In such a case, techniques are used that allow the resummation to all orders of the leading (LL) and next-to-leading (NLL) towers of logarithms of $p_{\rm T}/m$; in order to achieve the resummation, the heavy quark is effectively treated as massless.

The resummed (RS) and FO cross sections are therefore relevant to complementary regions in $p_{\rm T}$. The problem then arises whether to compare the data to FO or to RS predictions, since the inequality $p_{\rm T} \gg m$ cannot be unambiguously translated into a quantitative statement. It is thus desirable to write the single-inclusive cross section in a form that is sensible in the whole $p_{\rm T}$ range, that is, which interpolates between the FO result, relevant to the small- and intermediate-$p_{\rm T}$ regions, and the RS result, relevant to the large-$p_{\rm T}$ region. This is the aim of ref. [1] and ref. [2], relevant to hadro- and photoproduction respectively. In this letter, we shall concentrate on the latter, reviewing the formalism and presenting phenomenological predictions for

charm production at HERA.

Our master formula reads:

$$\text{FONLL} = \text{FO} \; + (\text{RS} \; - \; \text{FOM0}) \; \times G(m, p_{\rm T}) \;, \tag{1}$$

where FONLL (for Fixed Order plus Next-to-Leading Logarithms) will give sensible predictions in the whole $p_{\rm T}$ range, and FOM0 is obtained from FO by letting to zero all the terms suppressed by powers of $m/p_{\rm T}$. The subtraction of FOM0 from RS in eq. (1) is necessary to avoid double counting, since some of the logarithms appearing in RS are already present in FO. To be more precise, FONLL will have the following features:

- All terms of order $\alpha_{\rm em}\alpha_S$ and $\alpha_{\rm em}\alpha_S^2$ are included exactly, including mass effects;
- All terms of order $\alpha_{\rm em}\alpha_S\,(\alpha_S \log p_{\rm T}/m)^i$ and $\alpha_{\rm em}\alpha_S^2\,(\alpha_S \log p_{\rm T}/m)^i$ are included, with the possible exception of terms that are suppressed by powers of $m/p_{\rm T}$.

Finally, the function $G(m, p_{\rm T})$ is rather arbitrary, except that it must be a smooth function, and that it must approach one when $m/p_{\rm T} \to 0$, up to terms suppressed by powers of $m/p_{\rm T}$. In what follows, we shall use

$$G(m, p_{\rm T}) = \frac{p_{\rm T}^2}{p_{\rm T}^2 + c^2 m^2} \;, \tag{2}$$

with $c$ a free parameter. The practical implementation of eq. (1) is rather involved, especially in the photoproduction case; all the details can be found in ref. [2]

## 2 Charm production at HERA

In this section, we shall compare the predictions based upon eq. (1) to the experimental data for $D^*$ meson photoproduction obtained at the HERA collider by the H1 [3] and the ZEUS [4] collaborations. We set $m$=1.5 GeV, and the renormalization and factorization scales equal to the transverse mass of the quark, $\sqrt{p_{\rm T}^2 + m^2}$. The parton densities in the proton (photon) are given by the CTEQ5M1 (AFG) set. We set $\Lambda_{QCD}^{(5)} = 226$ MeV, as constrained by the CTEQ5M1 set; this value is almost identical to the central value of the PDG global fit. Finally, in order to simulate the hadronization of the bare $c$ quarks into $c$-flavoured mesons, we use the Peterson function, and multiply the results by the probability of a $c$ quark fragmenting into a $D^*$ meson, $P_{c \to D^*}$. In order to match the experimental conditions, we also need to apply cuts on the variables $y$ and $Q^2$, that enter the Weizsäcker-Williams function

(the latter variable is the upper limit of the photon virtuality squared). In particular, in the case of the ZEUS data, we have:

$$0.187 < y < 0.869, \quad Q^2 = 1 \text{ GeV}^2. \tag{3}$$

H1 has two data samples, corresponding to the two electron taggers (ETAG33 and ETAG44) used in the analyses:

$$0.29 < y < 0.62, \quad Q^2 = 0.01 \text{ GeV}^2: \qquad \text{ETAG33}; \tag{4}$$

$$0.02 < y < 0.32, \quad Q^2 = 0.009 \text{ GeV}^2: \qquad \text{ETAG44}. \tag{5}$$

We also point out that ZEUS use $P_{c\to D^*} = 22.2\%$, and H1 use $P_{c\to D^*} = 27\%$.

In figure 1, ZEUS data are compared to our theoretical predictions. The solid line is obtained from eq. (1), by setting $c = 5$ and the Peterson parameter $\epsilon = 0.02$. The dotted (dot-dashed) line is obtained with $c = 0$ and $\epsilon = 0.02$ ($c = 5$ and $\epsilon = 0.036$). Finally, the dashed line is the FO result (at NLO accuracy), with $\epsilon = 0.02$. It appears that none of the theoretical curves describes the experimental data particularly well, both in normalization and in shape. The impact of unknown power-suppressed terms, and of terms beyond NLO in the perturbative expansion of the resummed cross sections, can be roughly estimated by looking at the difference between the matched results obtained with $c = 5$ and $c = 0$ (solid and dotted curves respectively). This difference is non negligible, but it does not help in understanding the discrepancy with the data. On the other hand, the comparison between theory and H1 data, fig. 2, appears to be satisfactory. The same pattern is found in the rapidity and pseudorapidity spectra: H1 data are well reproduced by QCD, ZEUS data are not. A more detailed comparison between theory and HERA data will be presented in a forthcoming publication, where a complete study of the dependence upon the parameters entering the calculation (such as the mass and the scales) will be carried out.

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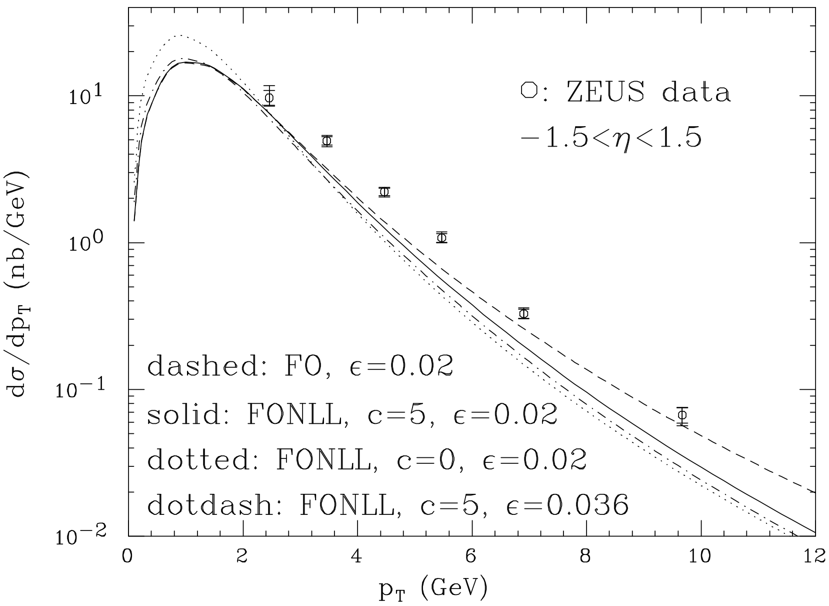


Figure 1. $p_{\rm T}$ spectrum of $D^*$ mesons, in the visible region of the ZEUS experiment. ZEUS data are compared to the theoretical predictions. See the text for details.

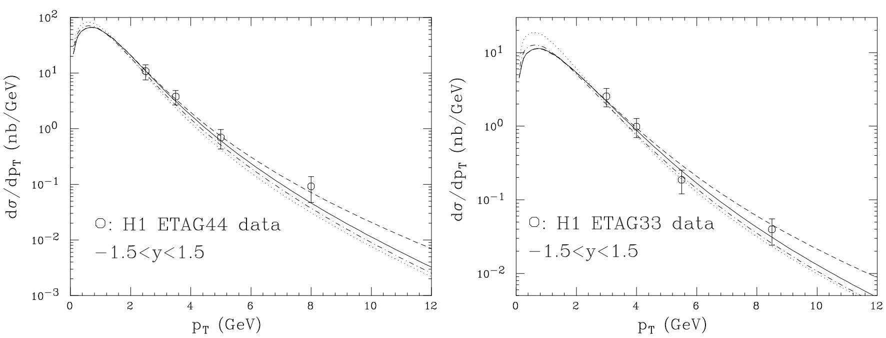


Figure 2. $p_{\rm T}$ spectrum of $D^*$ mesons, in the visible regions of the H1 experiment: ETAG44 (left panel), and ETAG33 (right panel). H1 data are compared to the theoretical predictions. The patterns of the theoretical predictions are as in fig. 1.